Non-Destructive Testing for Corrosion Detection and High-Temperature Applications

Yoseph Bar-Cohen, PhD; Stewart Sherrit, PhD; and Mircea Badescu, PhD, JPL/Caltech,

818-354-2610, yosi@jpl.nasa.gov

Chevron Fellows Visit at JPL
25 July, 2012

http//ndeaa.jpl.nasa.gov

Focus areas at the Advanced Technologies Group

	Small amplitude	Large amplitude
Low frequency (KHz)	Subsurface probing	Actuation & drilling
High frequency (MHz)	NDE & diagnostics	Medical treatment


Jet Propulsion Laboratory
California Institute of Technology
+ View the NASA Portal
Search JPL
JPL HOME | EARTH | SOLAR SYSTEM | STARS & GALAXIES | TECHNOLOGY
NDEAA
Nondestructive Evaluation and Advanced Actuators Technologies
Privacy/Copyright

The JPL's Nondestructive Evaluation and Advanced Actuators (NDEAA) Technologies lab is involved with innovative research and development (R&D) for space applications and technology transfer to other fields. It was established by Dr. Yoseph Bar-Cohen in May 1991 and it is part of his JPL's Advanced Technologies Group for which he is the Supervisor. Dr. Bar-Cohen and his Group members are internationally leading scientists in the field of electroactive materials and related mechanisms. The members of his Group are Dr. Mircea Badescu, Dr. Xiaoqi Bao, Dr. Zensheu Chang, Dr. Shyh-Shiuh Lih, and Dr. Stewart Sherrit. In addition, thru the JPL Educational Outreach Program professors, visiting scientists and students are participating in various studies at this lab. A homepage of the NDEAA Lab is part of the JPL's Science and Technology Website. The topics of R&D include novel actuators (mostly using electroactive ceramics and polymers), drilling and sampling systems, transducers, sensors, robotic mechanisms and NDE methods. The group conducts analytical modeling, development, design and fabrication of novel mechanisms and devices, performance testing and characterization as well as analysis that involve mechanical, electrical, magnetic and thermal parameters and interactions. Between Jan. 1, 2000 and Jul. 2, 2001, this NDEAA webhub had 1,000,007 (crossed the one million) total hits with 87,082 unique hits and by Sept. 3, 2001 it crossed the one hundred thousand (100,006) unique hits. The highest hits per day was recorded on March 9, 2005, where 9063 total hits and 3626 unique hits were recorded. This lab has been the subject of many articles in the news media. The NDEAA lab is involved with a broad range of R&D topics as described in the following clickable icons. The photos of the NDEAA members are clickable to their biography

Dr. Y. Bar-Cohen, Supervisor, Advanced Tech. Group & Senior Research Scientist | Dr. Mircea Badescu | Dr. Xiaoqi Bao | Dr. Zensheu Chang | Dr. Shyh-Shiuh Lih | Dr. Stewart Sherrit

The mechanisms that were developed at the NDEAA Lab are driven by elastic waves, mechanical vibrations and/or electroactive materials. Examples of these mechanisms include the ultrasonic/sonic driller/corer (USDC) that uses low preload and is developed for planetary sampling, deep drilling, high-temperature drilling, probing, sensing and in situ analysis making it a Lab-on-a-Drill. Also, they developed ultrasonic and surface acoustic wave motors and piezoelectric pumps that are driven by traveling flexural waves, This lab made major contributions to the field of electroactive polymers for use as actuators (artificial muscles) and, thru various forums, is mentoring the activity worldwide. Other technologies that are being explored include Haptic interfaces, high power ultrasound for medical treatment, ferroelectric source that generates various radiations and charged particles, wireless high power transmission, biomimetic technologies and geophysical probing using elastic waves. In addition to planetary applications, the developed devices and mechanisms have potential terrestrial applications for medical, commercial, construction and others. These efforts involve technical cooperation with scientists and engineers at various universities, research institutes, medical centers and industry in the USA and internationally. Further, the Nov. 2001 issue of the NASA Tech Briefs covered Dr. Bar-Cohen and NDEAA in a "Who's Who in NASA" article.

Research & Development Tasks
- *Biomimetics: Biologically-Inspired Technologies*
- *Advanced Actuators:*
  - *Electroactive Polymers (EAP) [artificial muscles, WW-EAP website, Bendbot, LoMMAs, etc.]*
  - *MEMICA (Haptic interfaces, telesurgery, Cyberglove, etc.)*
  - *Ultrasonic Actuators and Motors (USM, Piezo, etc.)*
- *Piezopump [miniature piezoelectric pump]*
- *Ultrasonic/Sonic Driller and Corer (USDC) -- Winner of the 2000 R&D Magazine Award for one of the 100 most innovative instruments*
- *Nondestructive Evaluation (NDE) [LLW, Intelligent NDE, etc.]*
- *Noninvasive Medical Diagnostics and Treatment [Blood Clots, Cancer, FMPUL, etc.]*
- *Noninvasive Geophysical Probing System (NGPS)*

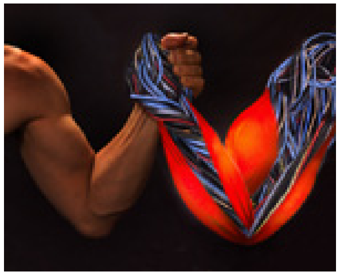
Applications of electromechanical materials in space mechanisms is one of the links:
http://eis.jpl.nasa.gov/ndeaa/nasa-mp/nasaonly/flight-hardware/piezo-in-space.htm

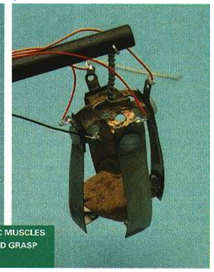
Applications to NDE

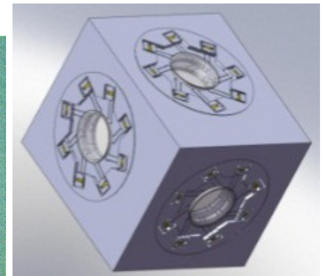
- Elastic waves as means of material characterization and monitoring changes
- Health monitoring via piezoelectric and eddy-current sensors
- Operation at extreme environments

Innovation at NDEAA

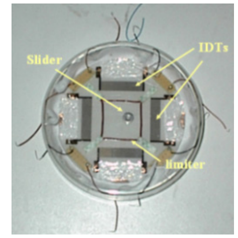
Electroactive Polymers (EAP)





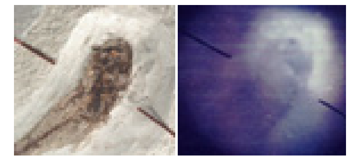


3D Barth Motor

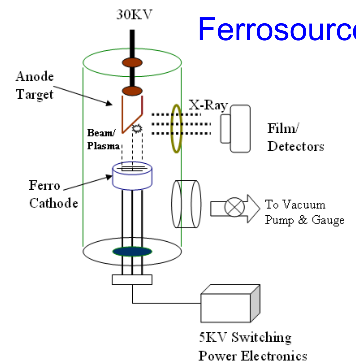


2 DoF SAW motor

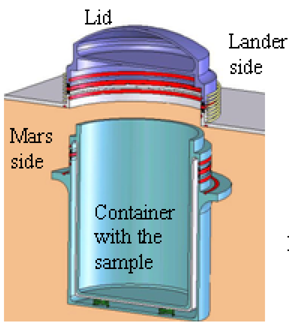
Ultrasonic Motors (USM)

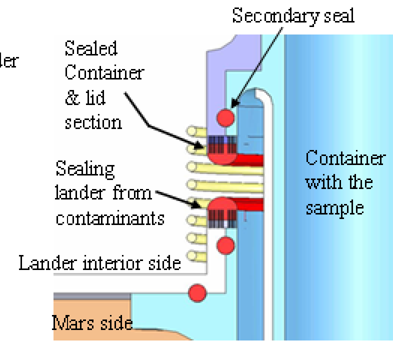


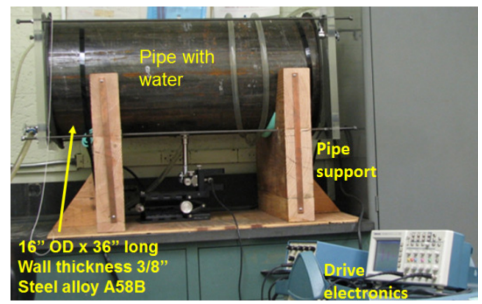
Ferrosource



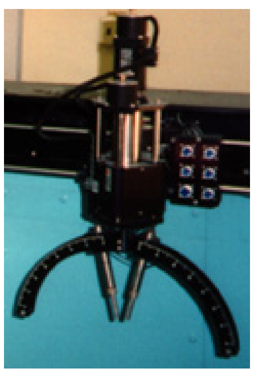
For MSR: Sample containerization using brazing and inductive heating



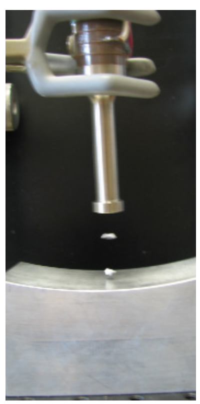




Monitoring condensation in steam pipes

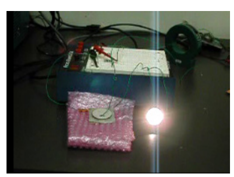


NDE - Measuring the elastic properties of composites using LLW



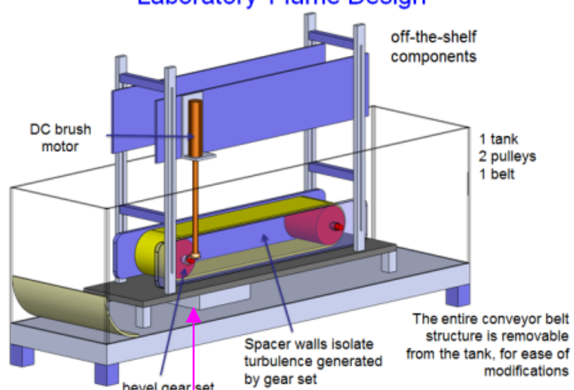
Acoustic levitation

Piezopump

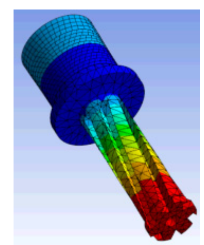


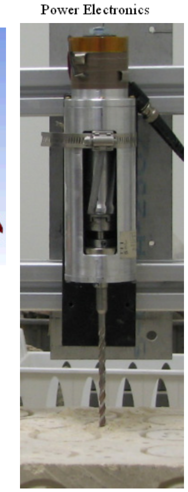
Wireless power feed-thru

Laboratory Flume Design



Sensor array for shear and pressure measurements



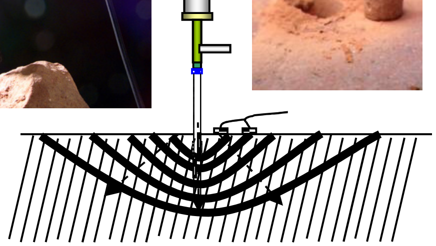


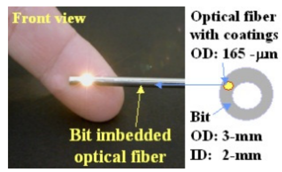
Single Piezo rotary-hammering drill

In-situ sampling and electroactive mechanisms

http://ndeaa.jpl.nasa.gov

USDC





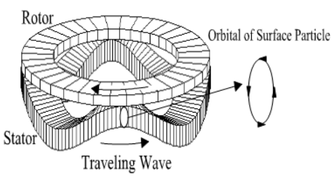
Probing, sampling and sensors platform

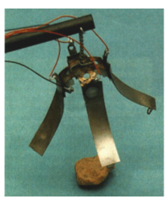
Gopher

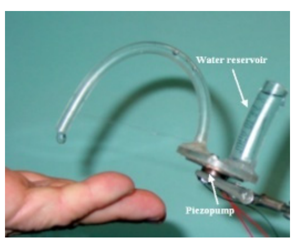
URAT

Concept → Mission

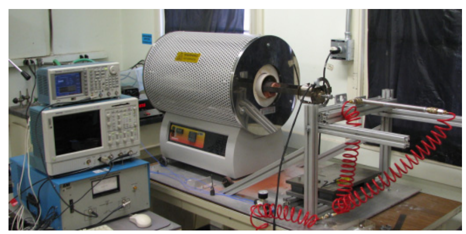
Actuators (USM, EAP, Piezopump)

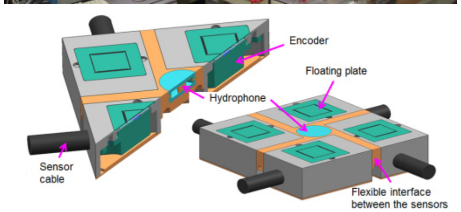




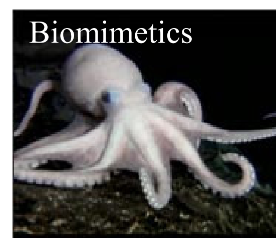


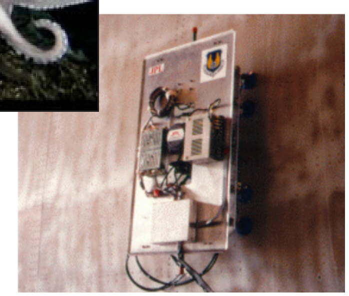
Other technologies (drilling, wireless power transmission, sensor arrays, etc.)



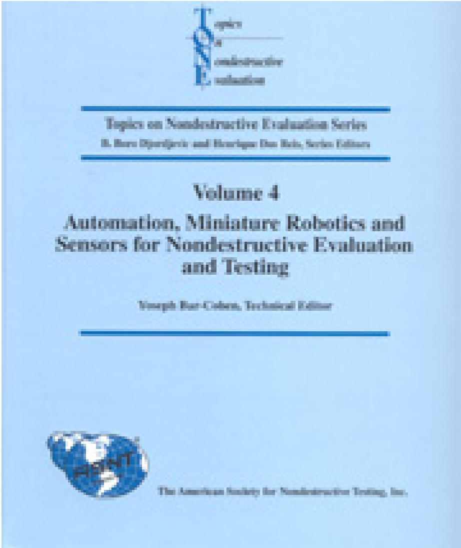


Robotics (MACS, MEMICA, Biomimetics)

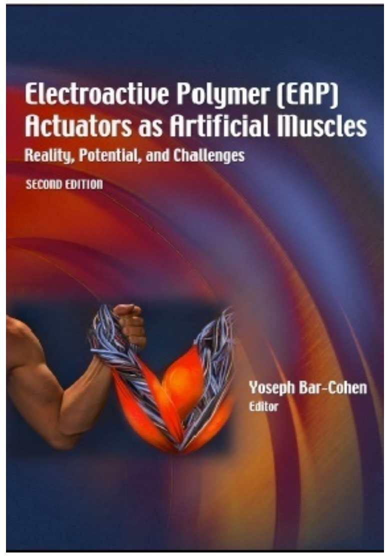




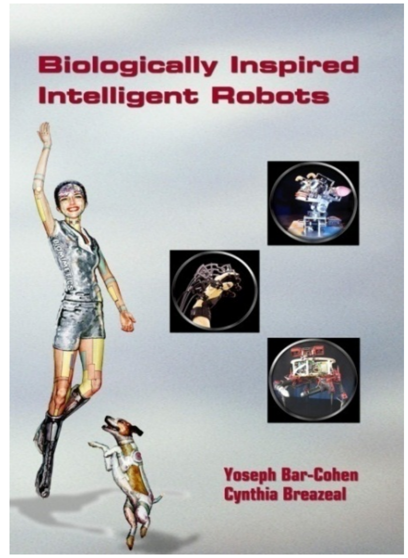
Components → Systems



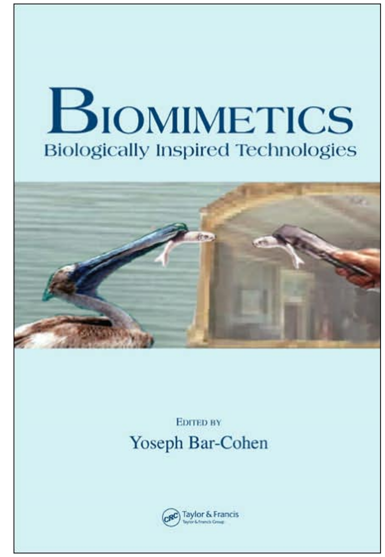
2000



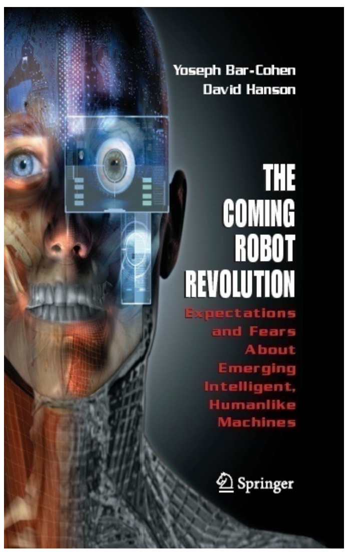
1st Ed. (2001)
2nd Ed. (2004)



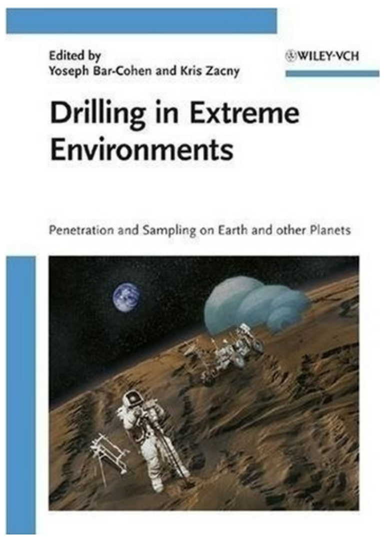
2003



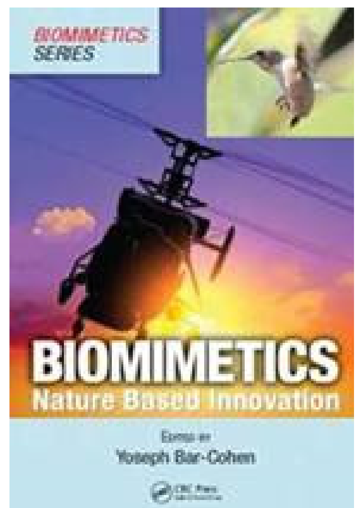
2005



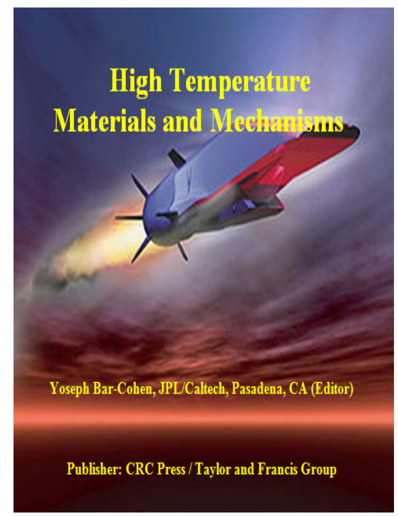
2009



2009



2011



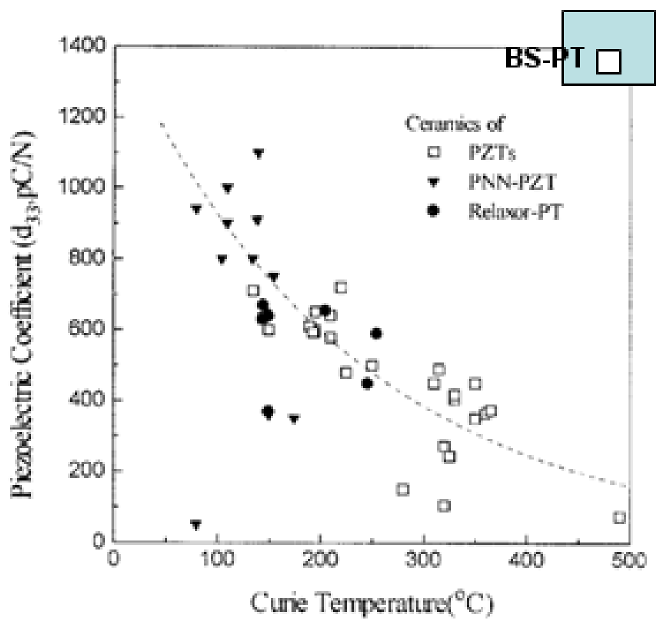
In preparation

http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm

HT piezoelectric materials (sensors and actuators)

Sensors that operate in harsh environments including extreme heat (300F-1,000F), cold, and corrosive gases (e.g. H2S, CO2, Sulfur Species).

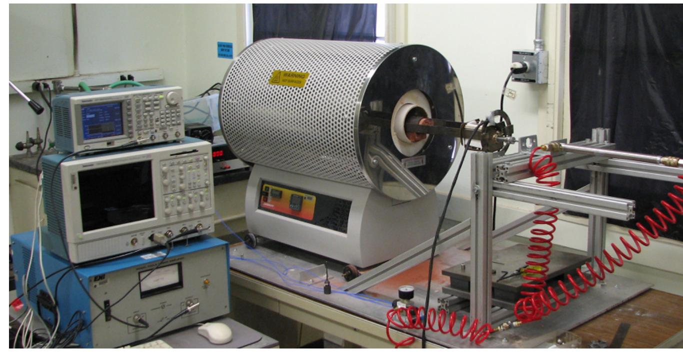
- Such piezoelectric materials as BSPT can be used to as high as 500^{o}C and we already demonstrate a ultrasonic/sonic drill with such actuator.
- One can use $LiNbO_3$ or maximize the response by using BSPT with optimal dopants content of
  - $Bi_4Ti_3O_{12}$, (1-x)$BiScO_{3-x}PbTiO_3$ (BSPT) , Mg modified BSPT, Bismuth Titanate, AIN
  - Effective electrodes

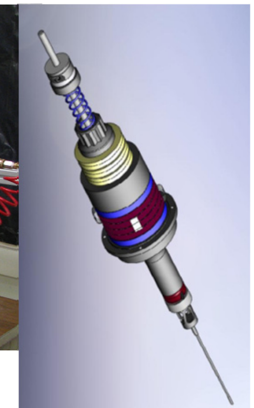


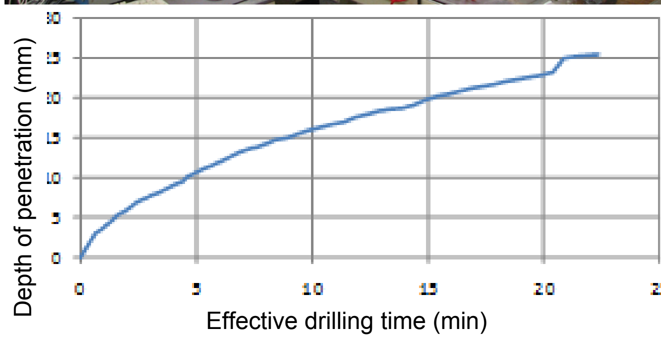
High Temperature Piezoelectric Actuated Sampler for Operation on Venus

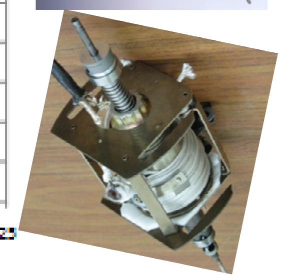
Objective

- Develop a sampler breadboard that can be operated at temperatures as high as 500°C
  - Develop new piezoelectric ceramic actuator with high electromechanical conversion efficiency at 500°C.
  - Produce ultrasonic/sonic driller and corer (USDC)-based sampler for cores and powdered cuttings









Accomplishment:

1. Developed novel design that makes the drill a rotary-hammer - the rotation is generated by the vibration of the piezoelectric actuator.
2. Isothermal tests of LiNbO3 piezoelectric discs at 500°C for 1000 hours yielded no change in properties
3. Novel horn and free-mass designs increased the coupling and maintain pre-stress and thermal stability and also induced rotation.
4. Bismuth Titanate with various doping of tungsten showed thickness coupling coefficient that is about 15 to 20% at 500°C**.**
5. Successfully drilled at 460°C thru a 25 mm thick brick sample in 21 minutes accumulated time. This is a significant accomplishment for this very challenging task and it required a lot of innovation to reach this success [submitted several related New Technology Reports]. The use of brick sample was chosen since more uniform properties were observed as opposed to natural rocks.

Advanced health monitoring of steam pipe systems

Under a contract from Consolidated Edison Company (Con-Edison) an ultrasonic system is being developed for monitoring the water condensation height in steam pipes thru the pipe wall at 250°C.

Phase I

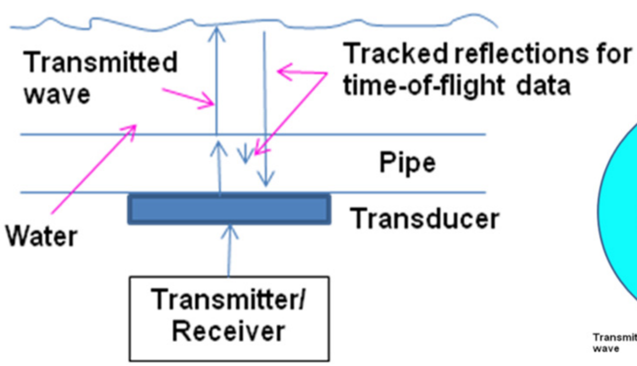
– A testbed was developed to simulate the pipe and its high temperature.

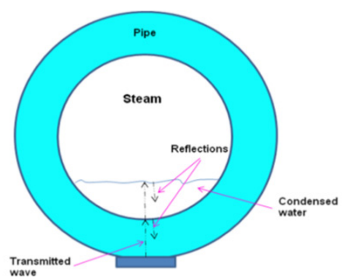
– An ultrasonic pulse/echo technique was developed where auto-correlation data processing was used

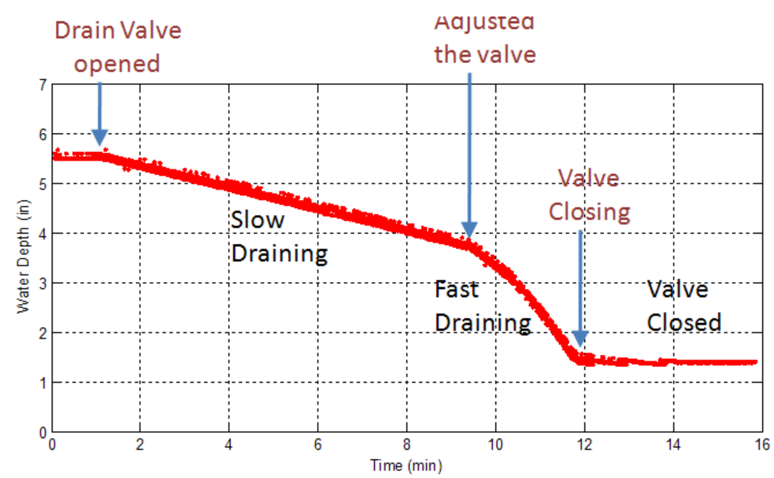
– A transducer was demonstrated to survive the condition of ≤250°C

Phase II

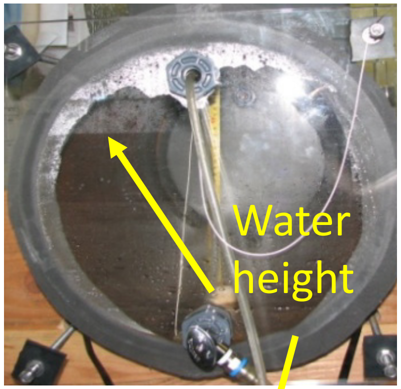
– A prototype system is being developed

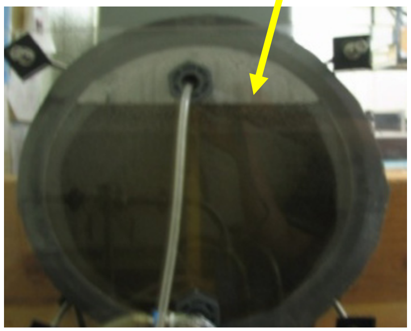


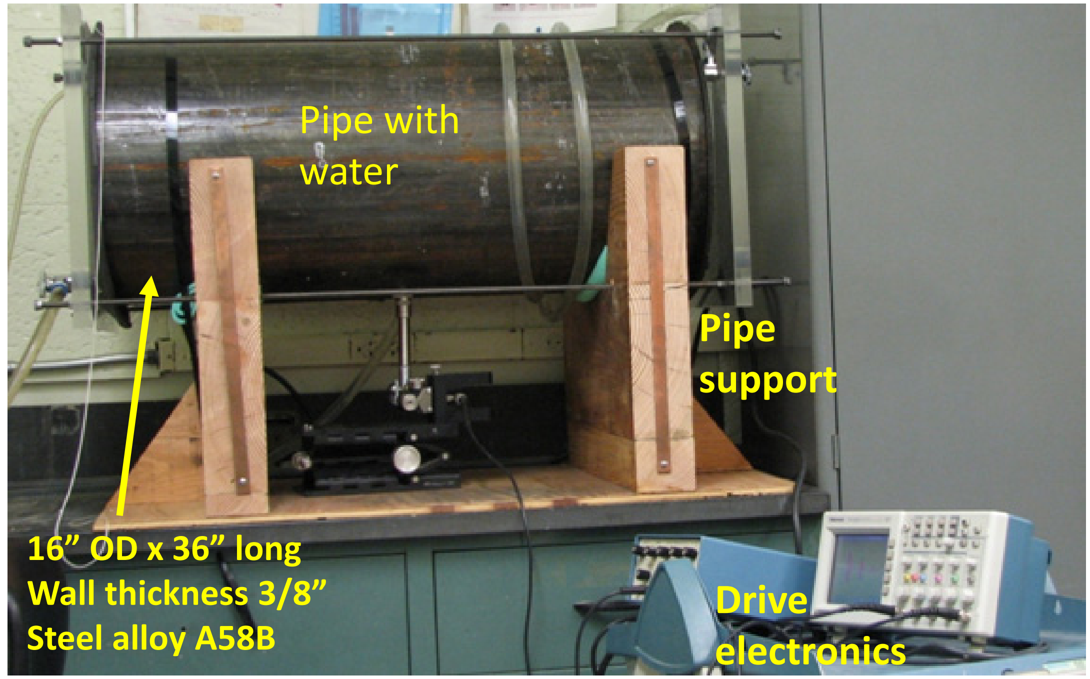


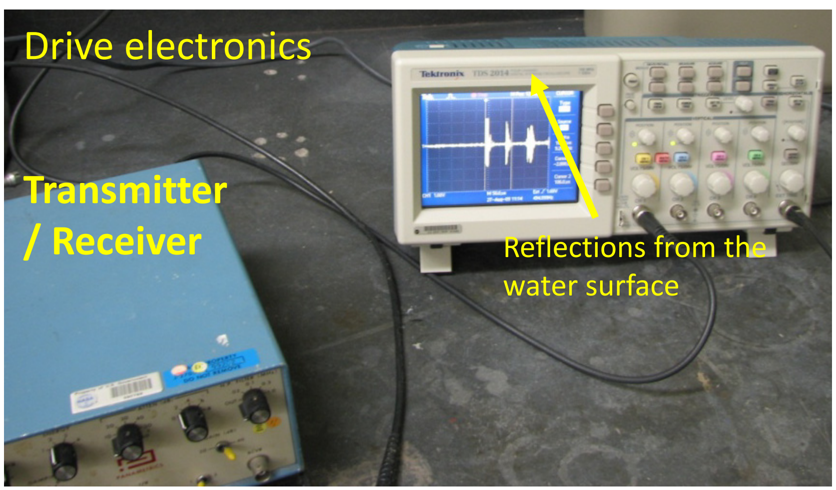


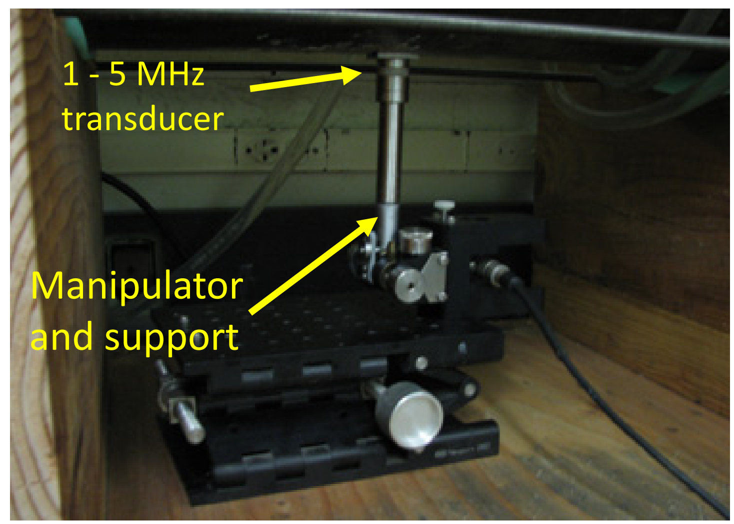
Test setup hardware, and drive electronics











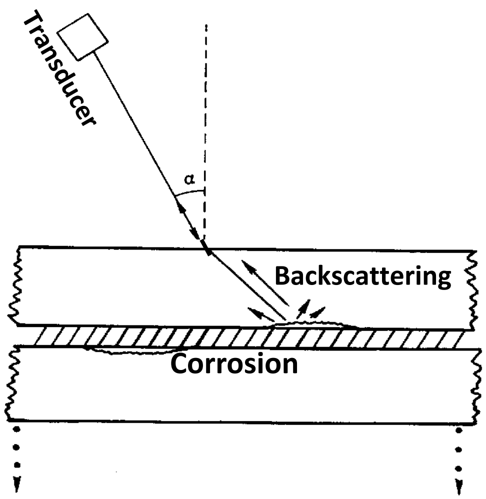
B1

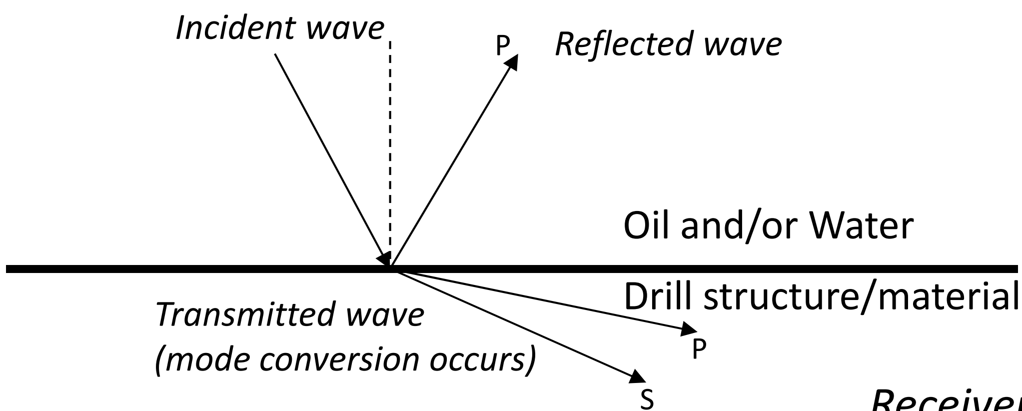
Slide 10

MB1 The arroww pinting to the scope has the tip in the wrong location
Badescu, Mircea (355N), 11/21/2011

Use of various ultrasonic wave modes and Eddy-Currents

- Sensors and smart materials that can detect or measure chemical reactions and/or certain kinds of corrosion by-products.
- Detection and characterization of corrosion damage.





Ultrasonic surface or plate waves can be used to detect corrosion or other types of damage and discontinuities.

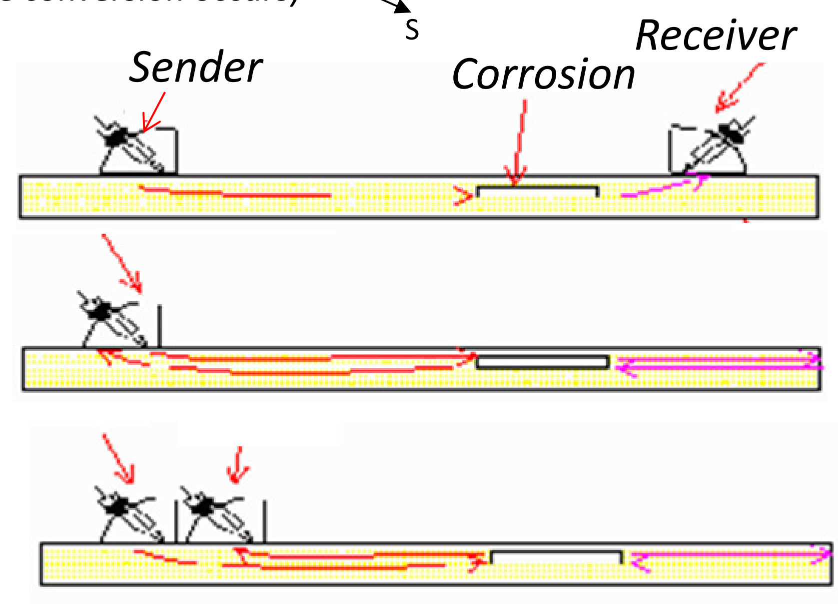
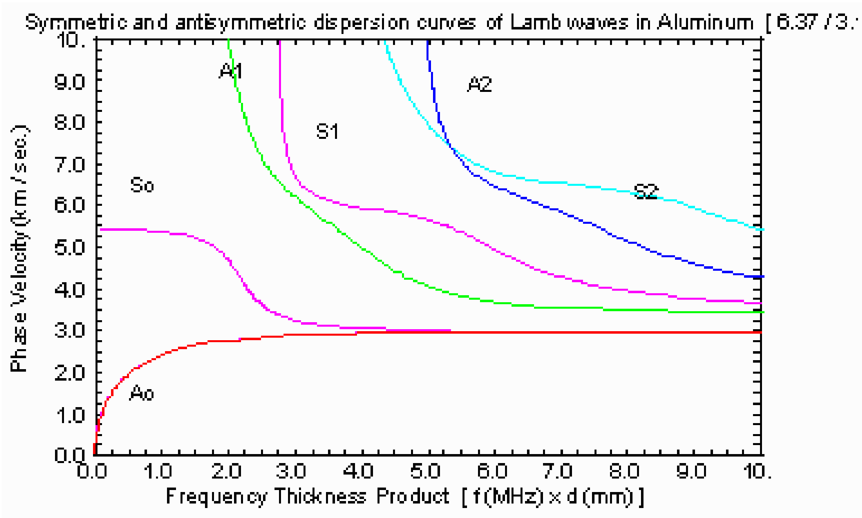
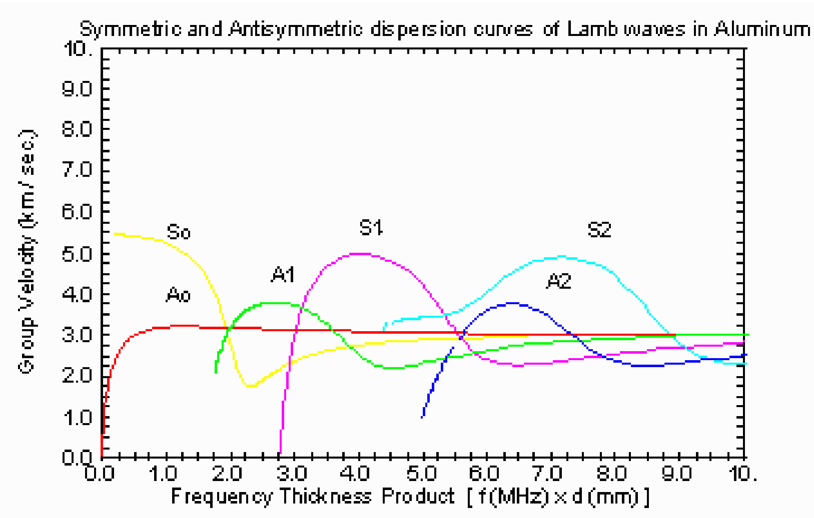
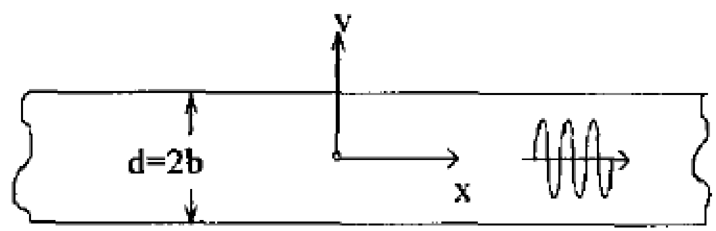


Plate wave modes

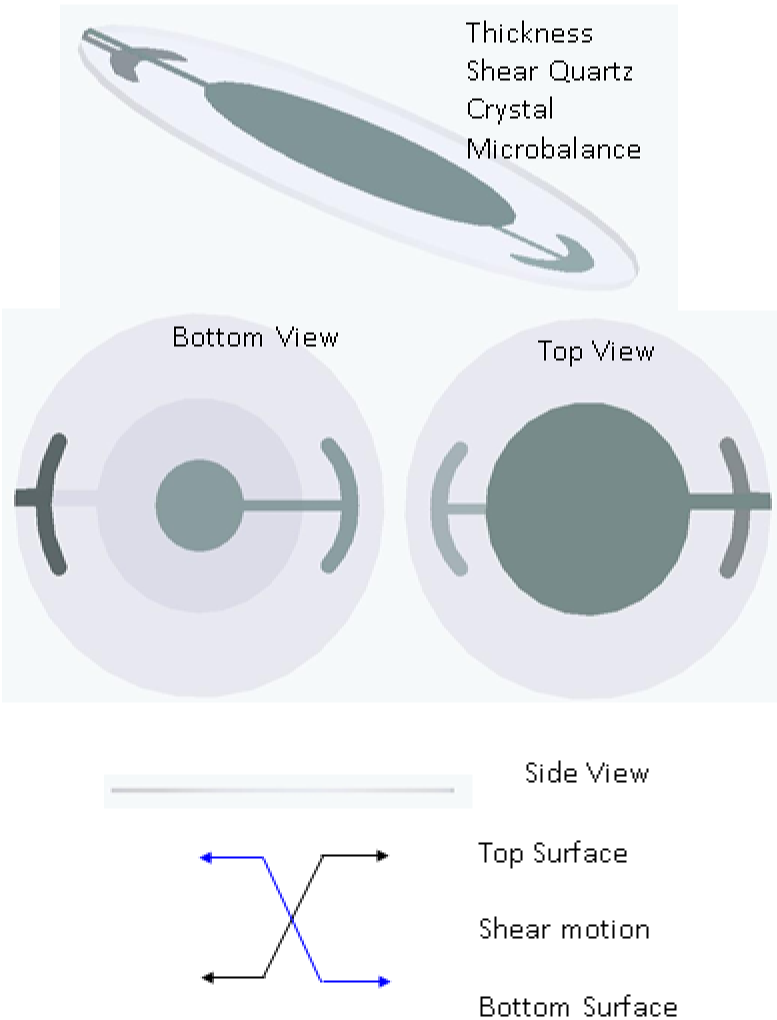




At certain incidence angle surface wave is generated and for when resonance occurs where the plate thickness is related to the wavelength plate waves are induced with symmetric or asymmetric mode.



Quartz Crystal Microbalance (QCM)



Sensitivity

$$m_o = \rho A t$$
$$= (2650\ kg/m^3)(5x10^{-5}\ m^2)(3x10^{-4}\ m)$$
$$= 0.04g$$

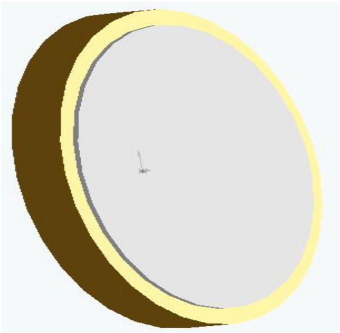
$$f = 6x10^6\ Hz$$

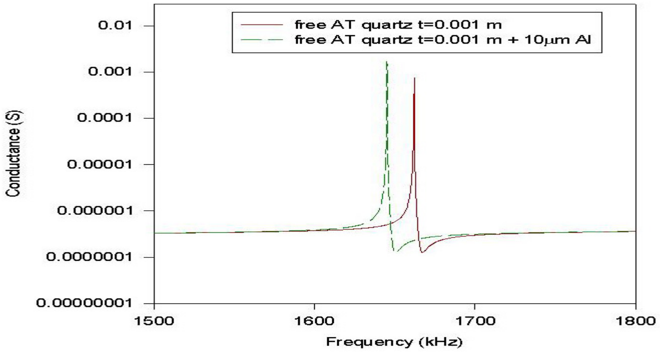
$$\Delta f = 0.2\ Hz$$

$$\Delta m = m_o \Delta f / f_o = <1.3\ ng$$

Mass Loading

$$\mathbf{Z}_L = i\rho_l A_l \mathbf{v}_l \tan\left(\frac{\omega L}{\mathbf{v}_l}\right) = i\rho_l A_l \mathbf{v}_l \left(\frac{\omega L}{\mathbf{v}_l}\right) = im\omega$$

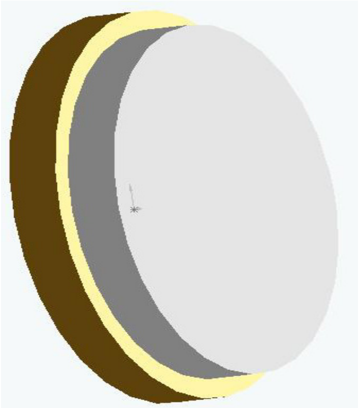


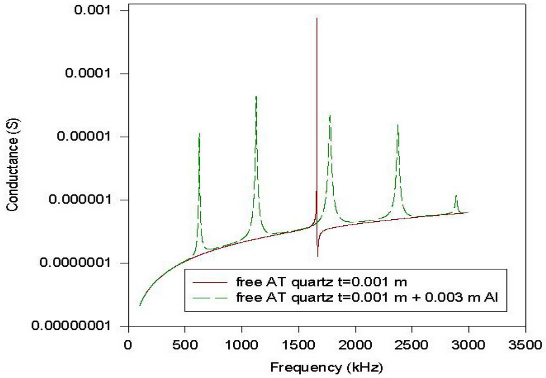


Elastic Loading

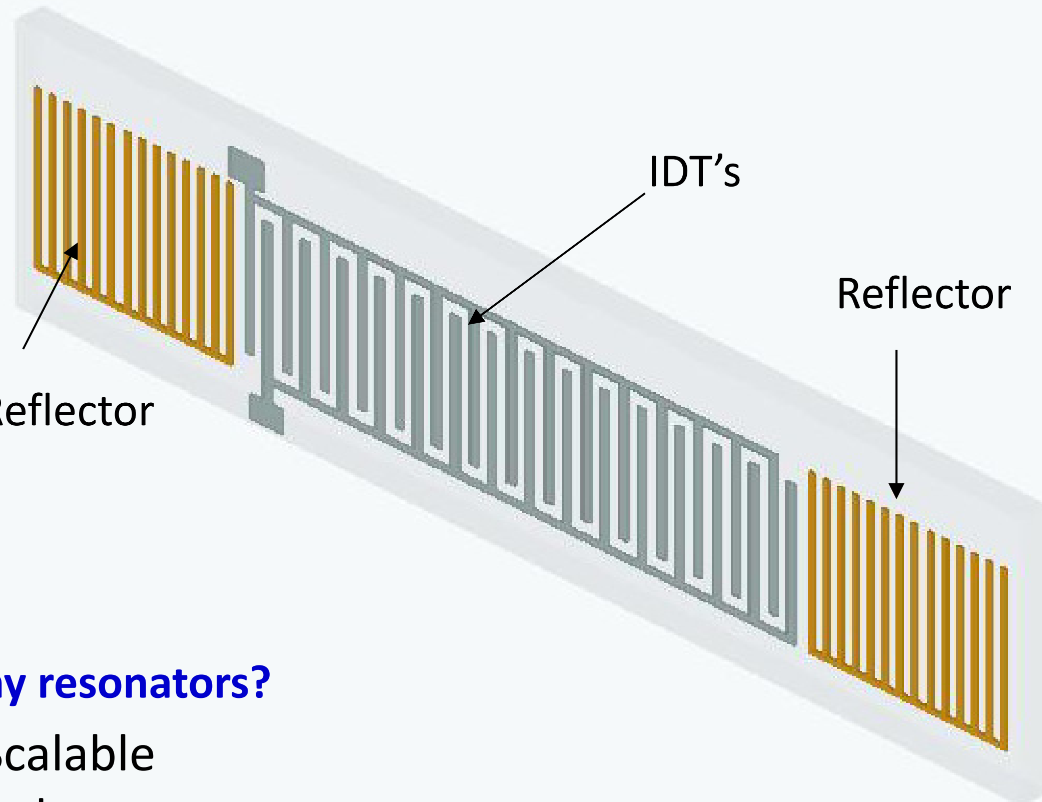
Load Impedance cannot be simplified and resonance in the layers are seen in spectra

$$\mathbf{Z}_L = i\rho_l A_l \mathbf{v}_l \tan\left(\frac{\omega L}{\mathbf{v}_l}\right)$$





SAW Resonator



SAW resonator

Sensitivity

$\Delta m = kA\Delta f/f^{2}$

$\approx < 0.1$ ng

Why resonators?

- Scalable
- Robust
- Low Power
- Can be designed for extreme environments (e.g.. High Temperature)
- Frequency can be measured very accurately
- Resonance frequency to first order independent of parasitic impedances